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The association of Step-based metrics and adiposity in the Hispanic community Health Study/Study of Latinos

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ABSTRACT

Objective: Examine cross-sectional and longitudinal associations of accelerometer measured step volume (steps/day) and cadence with adiposity and six-year changes in adiposity in the Hispanic Community Health Study/Study of Latinos (HCHS/SOL).

Methods: HCHS/SOL's target population was 60% female with a mean age of 41 years. Cross-sectional (n = 12,353) and longitudinal analyses (n = 9,077) leveraged adjusted complex survey regression models to examine associations between steps/day, and cadence with weight (kg), waist circumference (cm) and body mass index (kg/m^2). Effect measure modification by covariates was examined.

Results: Lower steps/day and intensity was associated with higher adiposity at baseline. Compared to those in the highest quartile of steps/day those in the lowest quartile have 1.42 95% CI (1.19, 1.70) times the odds of obesity. Compared to those in the highest categories of cadence step-based metrics, those in the lowest categories had a 1.62 95% CI (1.36, 1.93), 2.12 95% CI (1.63, 2.75) and 1.41 95% CI (1.16, 1.70) odds of obesity for peak 30-minute cadence, brisk walking and faster ambulation and bouts of purposeful steps and faster ambulation, respectively. Compared to those with the highest stepping cadences, those with the slowest peak 30-minute cadence and fewest minutes in bouts of purposeful steps and faster ambulation had 0.72 95% CI (0.57, 0.89) and 0.82 95% CI (0.60, 1.14) times the odds of gaining weight, respectively.

Conclusion: Inverse cross-sectional relationships were found for steps/day and cadence and adiposity. Over a six-year period, higher step intensity but not volume was associated with higher odds of gaining weight.

1. Introduction

Obesity is a recognized burden to our nation's health (Hales, et al., 2020) with disproportionate prevalence by race/ethnicity. In 2017–2018, U.S. Hispanic/Latinos had a higher prevalence of obesity (45%) than non-Hispanic whites (33%) and non-Hispanic Asians (17%) and a lower prevalence than non-Hispanic blacks (50%) (Hales, et al., 2020). Obesity is linked with cardiovascular disease (CVD), stroke, type 2 diabetes and additional comorbidities (WHO, 2014) that may lead to reduced quality of life, life-expectancy, and increased healthcare costs. The US Hispanic/Latino population is rapidly growing; by 2050, it is estimated that, one in every four people residing in the U.S. will be of Latino/a descent (Alcántara, 2017; Passel and D'Vera Cohn, 2008). If the disproportionate burden of obesity persists, a larger proportion of the U.S. Hispanic/Latino population will be impacted.

Physical activity (PA) is a modifiable behavior important for maintaining a healthy weight or achieving weight loss among other benefits (US Department of Health and Human Services, 2018). Sedentary behaviors (SB) are also modifiable behaviors linked with obesity (Ryan et al., 2015; Catrine et al., 2017); greater amounts of television viewing,

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screen time, and other seated activities are associated with weight gain (Hruby and Hu, 2015). A previous study examining the Hispanic Community Health Study/Study of Latinos (HCHS/SOL) found participants spent an average of 11.9 h/day in SB (Merchant et al., 2015).

Steps are a measurement of PA that encompass light, moderate, and vigorous PA (Bassett et al., 2017). Steps-based metrics are easily interpretable, trackable and broadly applicable measures of PA.

Steps/day reflect volume of daily ambulatory activity. Cadence, or steps/min, is an indicator of intensity of ambulatory movement and is highly correlated with speed ($r = 0.97$) and metabolic equivalents (METs) ($r = 0.94$) (Tudor-Locke et al., 2011). Cadence can describe free-living differences between incidental or sporadic movement, purposeful movement, or brisk walking and faster ambulation (Tudor-Locke et al., 2011; Tudor-Locke and Rowe, 2012; Tudor-Locke et al., 2018). Peak 30-min cadence reflects the highest "natural best effort" in a day7, (Tudor-Locke et al., 2011).

Habitual step volume (steps/day) and intensity can both be characterized with use of a single 7-day accelerometer administration (Keadle et al., 2017). Conflicting evidence exists for associations of steps/day and intensity (henceforth referred to as cadence), with adiposity and few studies have explored the longitudinal relationship15, (Preiss et al., 2015). Inverse (Catrine et al., 2017; Tudor-Locke and Rowe, 2012; Chan et al., 2003; Sumner et al., 2020; Hajna et al., 2018; Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015)and null relationships (Preiss et al., 2015; Sumner et al., 2020; Mitsui et al., 2008; Stanish and Draheim, 2007)have been reported in cross-sectional and longitudinal studies examining weight (Catrine et al., 2017), waist circumference (WC) (Catrine et al., 2017; Chan et al., 2003; Sumner et al., 2020; Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015), percentage body fat (Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Pillay et al., 2015), hip circumference, (Hornbuckle et al., 2005; Krumm et al., 2006), waist-to-hip ratio, (Hornbuckle et al., 2005; Thompson et al., 2004), trunk fat (Thompson et al., 2004; Krumm et al., 2006)and body mass index (BMI) (Catrine et al., 2017; Tudor-Locke and Rowe, 2012; Chan et al., 2003; Sumner et al., 2020; Hajna et al., 2018; Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015).

This study examines the cross-sectional and longitudinal associations of steps/day and cadence with adiposity and six-year changes in adiposity in the HCHS/SOL cohort, the largest well-characterized cohort of Hispanic/Latino adults in the U.S.

2. Methods

2.1. Study population

HCHS/SOL is a community-based prospective cohort study of Hispanics/Latinos designed to describe the prevalence of risk and protective factors for chronic conditions over time in Hispanics/Latinos. Details of the sampling design, and implementation have been previously published (LaVange et al., 2010; Sorlie et al., 2010). Briefly, this cohort consists of 16,415 self-identified Hispanic/Latino persons aged 18–74 years at screening from randomly selected households in four U.S. field centers (Chicago, IL; Miami, FL; Bronx, NY; San Diego, CA) with baseline clinic examination (2008 to 2011) and yearly telephone follow-up for primary cardiovascular and pulmonary endpoints. In 2014–2017 a second clinic visit was conducted. Recruitment involved a stratified two-stage area probability sample of household addresses in each field center. Individuals from identified households were contacted and screened for eligibility (living in the household, aged 18–74 years, able to attend a clinic visit and no plans to move within 6 months). All participants signed an informed consent. The institutional review boards of each field center, coordinating center, central laboratory, reading centers and the NHLBI approved this study. The study was registered at clincaltrials.gov as NCT02060344.

2.2. Physical activity and sedentary behavior

PA was measured using an Actical (MiniMiter Respironics®, Bend, OR) accelerometer (model 198-0200-03) at baseline. The Actical was initialized to capture steps in one-minute epochs. Participants were asked to wear the Actical on the right hip for 7 days; to engage in normal activities; and to only remove the accelerometer for swimming, showering and sleeping. Non-wear time was defined by the Choi algorithm as at least 90 consecutive minutes of zero counts with allowance of one or two minutes of nonzero counts if no counts were detected in a 30-minute window upstream and downstream of the 90-minute period (Choi, 2011). Adherence to the protocol was defined as having at least three days each with at least 10 h of wear time each. Further details, including accelerometer wear adherence, is available elsewhere (Evenson et al., 2015).

Steps/day was defined by a graduated step index with categorization of inactive, low activity, somewhat active, active and highly active (<5,000; 5,000–7,499; 7,500–9,999; 10,000–12,499 and ≥ 12,500 average total steps/day respectively) (Tudor-Locke, 2011). Cadence indicators were defined by average min/day at SB (0 steps/min), incidental or sporadic movement (1–39 steps/min), purposeful steps and faster ambulation (40–99 steps/min), and brisk walking and faster ambulation (≥100 steps/min) (Tudor-Locke et al., 2011; Tudor-Locke, 2011). Average peak 30-minute cadence was defined as mean steps/min for the highest 30 min of the day, not necessarily consecutive minutes. We examined bouted stepping at different cadence cut points including minutes at purposeful steps and faster ambulation (≥40 steps/min), slow to medium steps and faster ambulation (≥70 steps/min) and brisk walking and faster ambulation (≥100 steps/min). The bout was defined by at least 10-minutes at the cadence threshold. Interruptions were allowed for up to 20% of the time below the cadence threshold and < 5 consecutive minutes below the cadence threshold. Bouts started and ended with the cadence threshold. Bouted cadence metrics were categorized dependent on the distribution of the data. Minutes at brisk walking and faster ambulation were examined as four categories (no time at the specified cadence threshold and tertiles of steps/min > 0). Bouted cadence measures were examined as four categories (no bouted time at the specified cadence threshold and tertiles of bouted steps/min > 0). Minutes at all other cadence thresholds were categorized as quartiles. Average wear time was calculated as the average hours the accelerometer was worn/days.

2.3. Measures of adiposity

Anthropometric measures were collected at baseline and Visit 2 (V2) using standardized protocols (HCHS/SOL). Measurements of weight (kg) were obtained using a Tanita scale (TBF-300A), WC with a measuring tape and standing height (cm) with a fixed wall mounted stadiometer with a vertical backboard and moveable headboard. BMI was calculated as weight (kg)/height (m) (WHO, 2014). Home visits conducted at V2 (n = 348) did not measure height, thereby height from baseline was used to calculate BMI at baseline and V2.

Adults were classified as underweight (<18.5 kg/m^2), normal weight (≥18.5 to < 25 kg/m^2), overweight (≥25 to < 30 kg/m^2) and obese (≥30 kg/m^2) (WHO, 2014). Changes in weight, WC, and BMI were computed as V2 measurement-baseline measurement subtracted from measurement at V2. Weight change was defined as a substantial loss, loss, weight maintenance, gain and substantial gain (<-5%, −5 to −3%, −3% to 3%, 3% to 5%, and a > 5% change in weight, respectively) (Stevens et al., 2006).

2.4. Covariates

Covariates were collected at baseline. Covariates were defined as: age (continuous), sex (male/female), background (Central American/Cuban, Dominican/Mexican/Puerto Rican/South American/other), center (Bronx/Chicago/Miami/San Diego), years lived in the U.S. (<10 years/≥10 years/U.S. born), education (no high school diploma or GED/at most a high school diploma or GED/greater than high school [or GED] education), income (not reported/> $30,000/≤$30,000), longest held occupation (non-skilled worker/service worker/skilled worker/professional, technical-administrative, executive or staff/other), employment (retired/not retired/not currently employed/employed part-time/employed full-time), marital status (single/married or living with a partner/separated, divorced or widower), smoker (never/former/current), alcohol consumption (never/former/current), predicted total energy intake (National Cancer Institute predicted daily energy intake kcal derived from two 24-hour dietary recalls and a food propensity questionnaire) (Tooze et al., 2010), depressive symptoms assessed by the 10-item Center for Epidemiological Studies Depression Scale (CES-D 10) continuous summary score (Andresen et al., 1994) and mobility limitations assessed using 3-level Likert responses to two items from the Short Form-12 Version 2 [SF-12]) (Ware et al., 1996). The two SF-12 items assessed participant's ability to conduct "moderate activities" (e.g., moving a table, pushing a vacuum cleaner, bowling, or playing golf) and ability to climb several flights of stairs.

2.5. Statistical analysis

Among 16,415 cohort members, 12,353 were included in the cross-sectional analysis and of the 11,623 cohort members who returned to V2, 8,427 in the longitudinal analysis (Fig. 1).

To account for HCHS/SOL's complex sample design (stratification, clustering and sampling weights), complex linear regression models were used to separately estimate the association of steps/day and cadence with baseline measures of weight, WC, and BMI and measures of change in them. Complex survey logistic regression models were used to estimate the association of steps/day and cadence with baseline BMI category and weight maintenance over a 6-year period. Inverse probability weights (IPW) were leveraged to account for the high percentage of missingness due to non-adherence to the Actical protocol based on variables identified previously (Evenson et al., 2015). Sampling weights and IPW were multiplied together. Survey weights were trimmed and calibrated to the 2010 U.S. Census according to age, sex and Hispanic/Latino background of the field centers.

All models were adjusted for age, sex, center, Hispanic/Latino background, and years in the U.S (range, 3.4–9.6 years). Longitudinal models were further adjusted for years between visits. Models were additionally adjusted for relevant confounders identified through a directed acyclic graph. Potential confounding variables resulting in greater than a 10% change between minimally adjusted and further adjusted models were considered relevant confounders. To examine intensity independent of steps/day and SB, additional cadence models were further adjusted for total steps/day.

To remove multicollinearity of average wear time with sedentary time we used the residual approach to account for site-specific wear time variations as previously done in another HCHS/SOL paper for sedentary models (Qi et al., 2015). Specifically, we regressed sedentary time on wear-time, field center, and included an interaction term between HCHS/SOL field center and wear time, and then added the resulting residuals to the site-specific mean predicted values at 16 h of wear-time. This method was repeated to address multicollinearity between average total steps and cadence metrics when adjusting models for total volume.

Effect measure modification of the independent relationships between steps/day and adiposity by sex, age group (18–29, 30–39, 40–49, 50–59 years and ≥ 60 years), years in the U.S and occupation were assessed using interaction terms between step-metric and the modifier. A Bonferroni correction was used for the test of interaction terms to adjust for the number of hypotheses tested (0.05/93 ≤ 0.0005). All analyses accounted for the complex survey design and survey weights using survey procedures in SAS version 9.4 (SAS Institute).

3. Results

3.1. Study population characteristics of the cross-sectional analysis

The target population of HCHS/SOL was 60% female and had a mean (standard error [SE]) age of 41 (0.3) years. The mean (SE) baseline weight, WC and BMI were 79 (0.3) kg, 97 (0.3) cm and 29 (0.1) kg/m^2, respectively. Adults had a mean step count of 7,829 steps/day (median, 6,998 steps/day; range, 1,238–22,355 steps/day), mean (SE) accelerometer wear time of 16 (0.1) hours/day (range, 10–23 h/day), and a mean (SE) peak 30-minute cadence of 76 (0.4) steps/min. On average, adults spent 670 (3.8) min/day sedentary, 221 (1.3) min/day in incidental or sporadic movement, 51 (0.6) min/day in purposeful stepping and faster ambulation, and 12 (0.3) min/day in brisk walking and faster ambulation. Table 1 provides details on other baseline demographic and lifestyle characteristics by graduated step-index (Table 1).

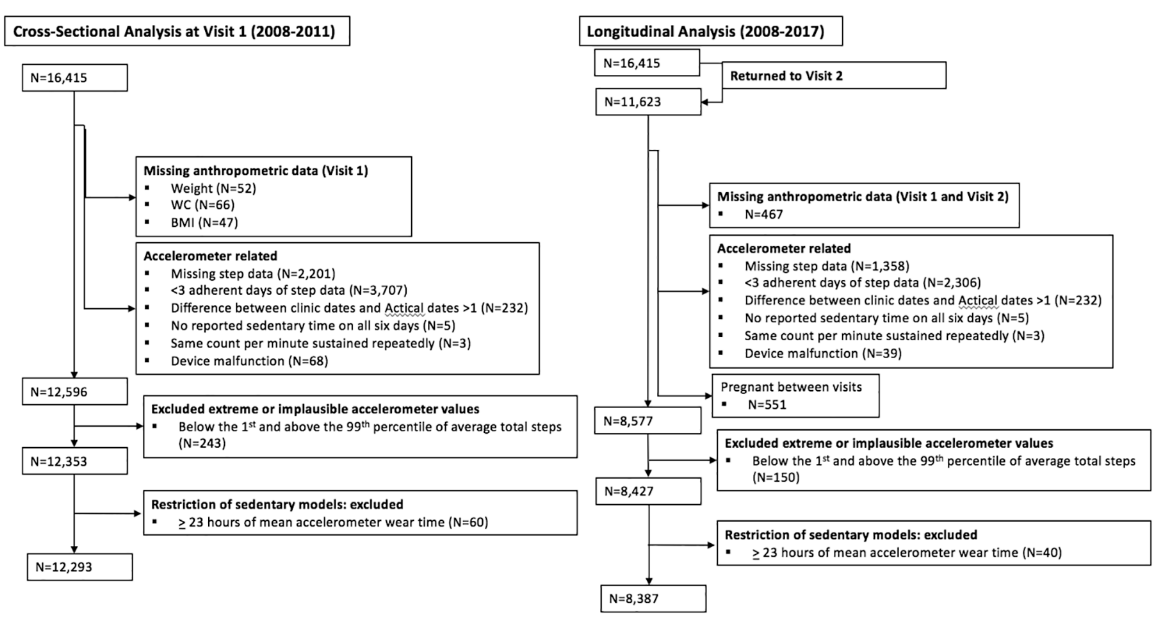

Fig. 1. Cross-Sectional and longitudinal analyses exclusions; HCHS/SOL.

Table 1
Baseline Characteristics by Graduated Step Index Distribution among U.S. Hispanic/Latino adults (n = 12,353); HCHS/SOL (2008–2011)**.

	N	Inactive (<5,000 average total steps) (*n* = 3585)	Low activity (5,000–7,499 average total steps) (*n* = 3268)	Somewhat active (7,500–9,999 average total steps) (*n* = 2408)	Active (10,000–12,499 average total steps) (*n* = 1505)	Highly Active (>12,500 average total steps) (*n* = 1587)
%		29.0	26.5	19.5	12.2	12.8
Age (SE), years		44.1 (0.5)	40.7 (0.4)	39.0 (0.5)	39.3 (0.6)	39.4 (0.5)
Sex (%)						
Men	4896	37.1	42.8	50.0	57.5	65.9
Women	7457	62.9	57.3	50.0	42.6	34.1
Hispanic/Latino background (%)						
Central American	1250	7.6	7.1	8.7	7.6	5.9
Cuban	1641	31.2	19.2	15.5	14.3	11.6
Dominican	1136	7.5	11.6	11.1	12.0	8.8
Mexican	5107	4.1	5.4	5.8	5.1	5.2
Puerto Rican	2027	3.5	4.4	3.5	3.3	4.0
South American	831	7.6	7.1	8.7	7.6	5.9
Mixed/Other/Missing	335	31.2	19.2	15.5	14.3	11.6
Center (%)						
Bronx	3065	21.4	27.4	31.5	33.7	36.8
Chicago	3252	14.0	15.1	16.0	17.7	18.6
Miami	2845	40.4	29.0	25.9	21.9	19.9
San Diego	3191	24.2	28.5	26.6	26.8	24.7
Education (%)						
No High School or GED	4757	31.7	30.5	33.4	32.4	34.6
High School or GED	3094	26.8	27.4	28.0	27.0	32.9
Above High School or GED	4477	41.5	42.1	38.6	40.5	32.6
Employment*						
Employed full time	4239	22.4	32.3	37.1	40.5	49.3
Employed part time	2088	15.0	15.3	18.3	19.3	21.6
Not currently employed	5889	62.6	52.4	44.6	40.2	29.2
Income (%)						
<$30,000	7891	66.0	63.8	62.2	61.7	64.0
≥$30,000	3773	26.5	30.6	32.9	34.4	32.3
Not reported	689	7.5	5.6	4.9	4.0	3.7
Longest held occupation (%)						
Non-skilled worker	3673	21.5	23.9	23.6	31.4	32.5
Service worker	1747	17.6	14.3	17.6	13.5	14.3
Skilled worker	2680	20.4	21.1	23.3	22.0	22.2
Professional/technical, administrative/executive	1751	18.2	18.1	16.8	13.1	9.3
Other	2374	22.3	22.6	18.8	20.0	21.7
Years in the U.S. (%)						
U.S. born	2003	20.7	22.0	23.3	24.9	24.7
>10 years in the U.S.	7463	50.0	49.4	47.6	49.6	48.1
<10 years in the U.S.	2873	29.3	28.6	29.1	25.6	27.2
Smoking (%)						
Never	7562	60.7	62.9	64.0	62.5	58.4
Former	2538	18.8	16.9	15.1	16.9	19.4
Current	2237	20.5	20.2	20.9	20.6	22.2
Marital Status (%)						
Single	3135	32.4	31.9	37.8	37.2	36.8
Married/Living with a Partner	6631	46.9	51.5	48.9	49.5	49.6
Separated/Divorced/Widow (er)	2559	20.6	16.6	13.2	13.4	13.7
Symptoms of Depression						
CESD10[†] score mean (SE)		7.4 (0.2)	7.0 (0.2)	6.7 (0.2)	6.3 (0.2)	6.6 (0.2)
Accelerometer wear time mean (SE)		15.2 (0.1)	15.7 (0.1)	16.1 (0.1)	16.4 (0.1)	17.1 (0.1)
Total energy intake (kcal) mean (SE)		1901.7 (14.6)	1955.6 (15.3)	1993.2 (19.1)	2057.5 (23.2)	2128.7 (23.3)
Baseline weight (kg) mean (SE)		80.8 (0.6)	78.2 (0.5)	77.7 (0.7)	78.2 (0.8)	78.0 (0.7)
Baseline waist circumference (cm)		100.0 (0.5)	97.0 (0.4)	96.0 (0.7)	96.0 (0.6)	95.1 (0.5)
Baseline BMI (kg/m^2)		30.45 (0.2)	29.3 (0.2)	28.9 (0.3)	28.6 (0.2)	28.5 (0.2)
BMI Category[¥]						

(*continued on next page*)

Table 1 (*continued*)

	N	Inactive (<5,000 average total steps) (n = 3585)	Low activity (5,000–7,499 average total steps) (n = 3268)	Somewhat active (7,500–9,999 average total steps) (n = 2408)	Active (10,000–12,499 average total steps) (n = 1505)	Highly Active (>12,500 average total steps) (n = 1587)
Normal	2433	19.3	22.7	25.4	22.1	23.3
Overweight	5091	45.8	37.8	36.5	35.1	34.7
Obese	4740	33.1	38.6	37.3	41.6	41.6
Underweight	89	1.7	0.9	0.8	1.3	0.4
Mobility limitations, moderate[¥¥]						
Yes, limited a lot	1003	10.0	6.4	4.9	4.1	5.8
Yes, limited a little	1879	15.7	11.6	11.3	11.2	9.9
No, not limited at all	9452	74.3	82.0	83.8	84.7	84.3
Mobility limitations climbing several flights of stairs						
Yes, limited a lot	1445	13.1	9.7	7.8	5.9	8.0
Yes, limited a little	2676	22.5	17.8	18.1	15.3	16.0
No, not limited at all	8208	64.4	72.4	74.1	78.8	76.1

* Employed full time: >35 h/week in one job or more than one job, employed part time (≤35 h/week).
†10-Item Center for Epidemiology Depression Scale (CES-D10).
††Global Physical Activity Questionnaire (GPAQ).
¥ Normal weight: 18.5 to < 25 kg/m^2, overweight: 25.0 to < 30 kg/m^2, obese: ≥30 kg/m^2, underweight: <18.5 kg/m^2.
¥¥ Activities such as moving a table, pushing a vacuum cleaner, bowling, or playing golf.
**All statistics are weighted and account for HCHS/SOL complex survey design.

3.2. *Cross-sectional associations of steps/day and adiposity*

Steps/day demonstrated inverse relationships with all measures of adiposity (Fig. 2).

Step index adjusted for: age, sex, center, background, years in the U.S., employment, occupation, income, mobility limitations (climbing stairs), smoking, marital status, predicted total energy intake and average accelerometer wear time. Step cadence adjusted for: age, sex, center, background, years in the U.S., mobility limitations (climbing stairs), smoking and average accelerometer wear time per day.

When adjusted for confounders (Fig. 2) adiposity metrics of those inactive were higher than those highly active (inactive adjusted mean weight: 85.3 kg, WC: 102.7 cm, and BMI: 31.3 kg/m (WHO, 2014); highly active adjusted mean weight: 79.1 kg, WC: 97.9 cm and BMI 29.9 kg/m^2). Those who took the fewest daily steps compared to those who took the most steps had a 1.42 95% CI (1.19, 1.70) times the odds of obesity (Fig. 3).

Step index adjusted for: age, sex, center, background, years in the U.S., employment, occupation, income, mobility limitations (climbing stairs), smoking, marital status, predicted total energy intake and average accelerometer wear time. Step cadence adjusted for: age, sex, center, background, years in the U.S., mobility limitations (climbing stairs), smoking and average accelerometer wear time per day.

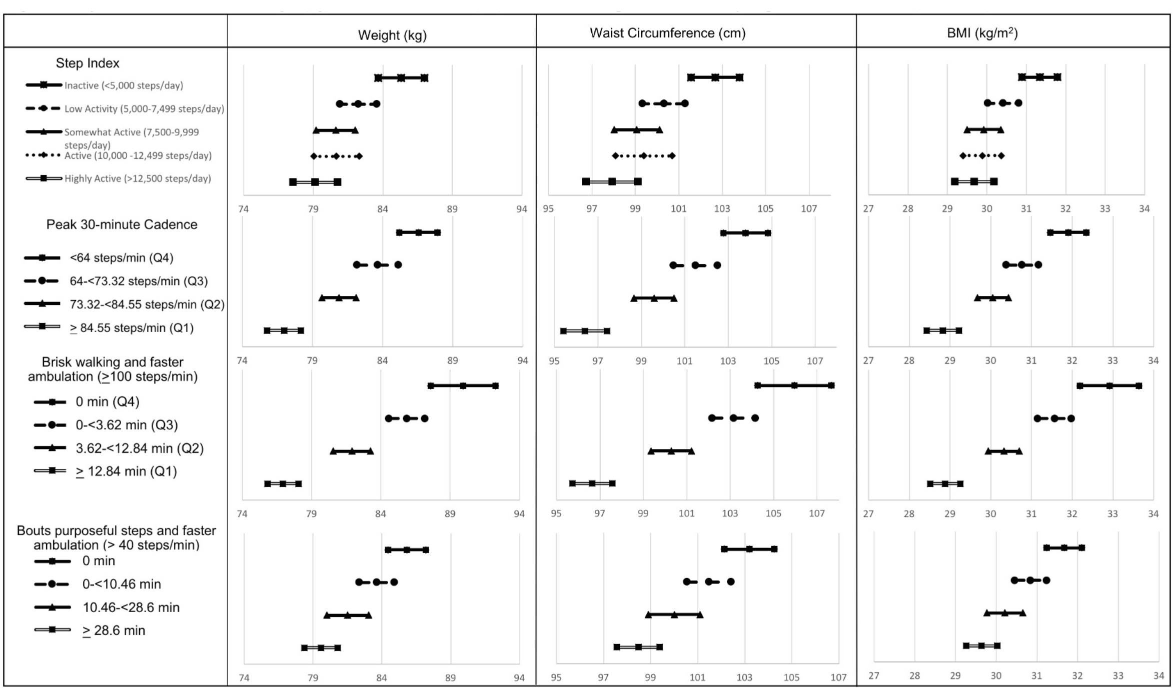

Fig. 2. Adjusted means of baseline weight (kg), waist circumference (cm) and BMI (kg/m^2) and respective 95% confidence intervals by step-based metrics; HCHS/SOL (2008–2011).

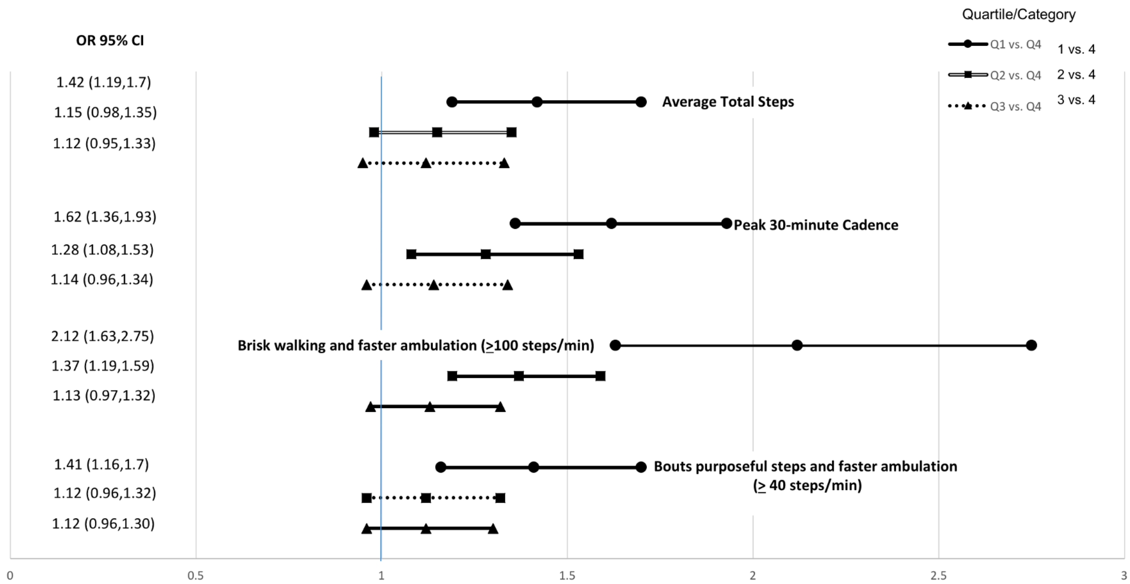

Fig. 3. The odds of obesity and 95% confidence intervals in quartiles/categories 1–3 of step-based metrics compared to quartile/category 4 at baseline; HCHS/SOL (2008–2011).

3.3. *Cross-sectional associations of step cadence and adiposity*

Peak 30-minute cadence, minutes at a brisk walk and faster ambulation, and minutes in bouted stepping at purposeful steps or faster ambulation demonstrated inverse associations with all measures of adiposity (Fig. 2). Adjusted mean weight, for those in the lowest quartile and categories of mean peak 30-minute cadence, minutes in a brisk walk and faster ambulation, and minutes in bouted steps of purposeful steps and faster ambulation were 86.6 kg, 89.9 kg, and 85.8 kg, respectively whereas those in the highest quartile and categories were 77.0 kg, 76.9 kg, and 79.6 kg, respectively (Fig. 2). Adjusted mean WC for those in the lowest quartile and categories of mean peak 30-minute cadence, minutes in a brisk walk and faster ambulation and minutes in bouted purposeful steps and faster ambulation were 103.8 cm, 106.0 cm and 103.2 cm respectively, whereas those in the highest quartile and categories were 96.4 cm, 96.7 cm and 98.5 cm, respectively (Fig. 2). Adjusted mean BMI for the lowest quartile and categories of mean peak 30-minute cadence, minutes in a brisk walk and faster ambulation and minutes in bouted steps of purposeful steps and faster ambulation were 31.9 kg/m^2, 32.9 kg/m^2 and 31.7 kg/m^2, respectively whereas those in the highest quartile and categories were 28.8 kg/m^2, 30.3kg/m^2 and 29.6 kg/m^2, respectively (Fig. 2). Adults in the lowest quartile and categories of mean peak 30-minute cadence, minutes in a brisk walk and faster ambulation and minutes in bouted purposeful steps and faster ambulation had a 1.62 95% CI (1.36, 1.93), 2.12 95% CI (1.63, 2.75) and 1.41 95% CI (1.16, 1.70) times the odds of obesity compared to adults in the highest quartiles and categories, respectively (Fig. 3). SB was not associated with adiposity (Table S1).

3.4. *Cross-sectional interactions of step-based metrics and adiposity*

Significant interactions between minutes in incidental or sporadic movement and age were found for weight and BMI (Tables S2–S4). Among those $\geq$ 60 years of age, those in the highest quartile of minutes in incidental or sporadic movement had significantly higher mean measures of weight and BMI than those in the lowest quartile. No significant differences in adiposity across quartiles or categories of step-based metrics were found for all other age categories (Tables S3 & S4). Interactions between step-based metrics and sex, years in the U.S. and occupation were non-significant for all measures of adiposity (Table S2).

3.5. *Longitudinal associations of steps/day and cadence with changes in adiposity*

Adults who accumulated more steps/day had greater increases in weight and BMI over six years compared to adults who accumulated fewer steps/day (Table S5); further adjustment for confounders attenuated associations (Table S5). A faster peak 30-minute cadence, and more minutes in a brisk walk and faster ambulation and bouted purposeful steps and faster ambulation were associated with greater weight and BMI change (Fig. 4).

Step index adjusted for age, sex, center, background, years in the U. S., employment, occupation, income, mobility limitations (moderate), marital status, predicted total energy intake, CESD10, and average accelerometer wear time per day. Step cadence adjusted for: age, sex, center, background, years in the U.S., employment, years between visits and average accelerometer wear time per day.

Adjusted mean changes in weight for those in the lowest quartile and categories of mean peak 30-minute cadence, minutes in a brisk walk and faster ambulation, and minutes in bouted purposeful steps and faster ambulation were −0.5 kg, 0.31 kg, and −0.66 kg, respectively whereas, in the highest quartile and categories they were 1.5 kg, 1.6 kg and 1.3 kg, respectively (Fig. 4). Consistently, in examination of weight maintenance, those in the lowest compared to highest quartile and categories of peak 30-minute cadence and minutes in bouts of purposeful steps and faster ambulation had 0.72 95% CI (0.57, 0.89) and 0.82 95% CI (0.60, 1.14) times the odds of gaining weight, respectively (Fig. 5).

Step index adjusted for age, sex, center, background, years in the U. S., employment, occupation, income, mobility limitations (moderate), marital status, predicted total energy intake, CESD10, and average accelerometer wear time per day.

Minutes in SB (Table S6) and minutes in incidental or sporadic movement (Table S7) were not associated with changes in adiposity. No significant interactions were found between step-based metrics and age, sex, occupation and years in the U.S. for associations with changes in adiposity (Table S8).

4. Discussion

In this community-based cohort of U.S. Hispanic/Latino adults with accelerometer-measured PA, we found steps/day and cadence had inverse cross-sectional relationships with weight, BMI, and WC. Adults

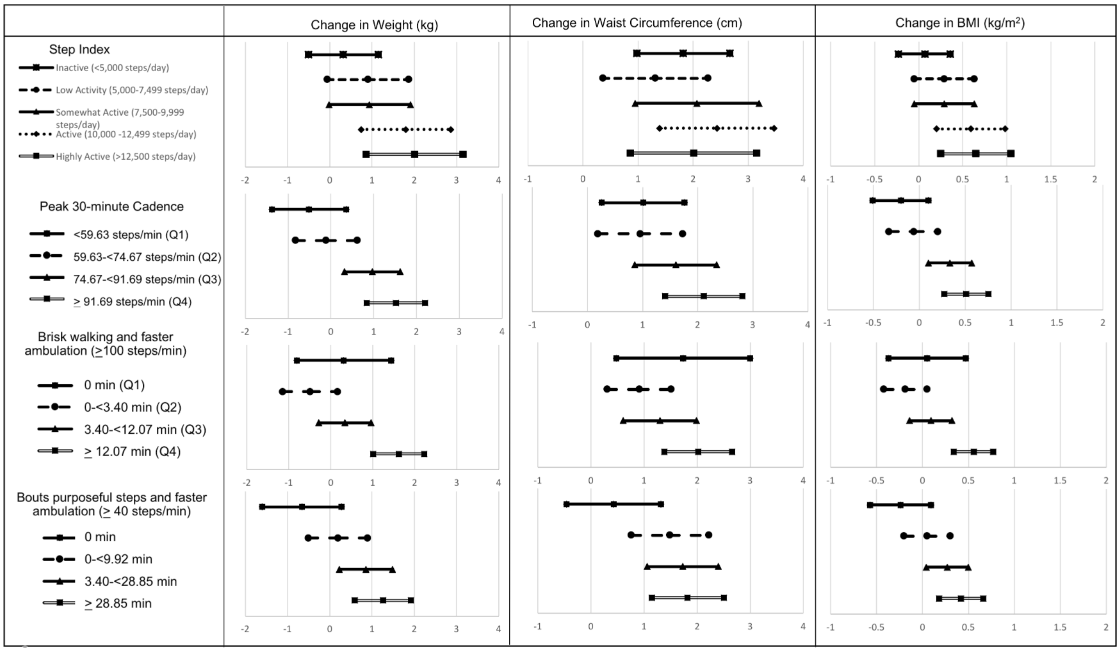

Fig. 4. Adjusted mean changes in weight (kg), waist circumference (cm) and BMI (kg/m^2) and respective 95% confidence intervals by step-based metrics; HCHS/SOL (2008–2017).

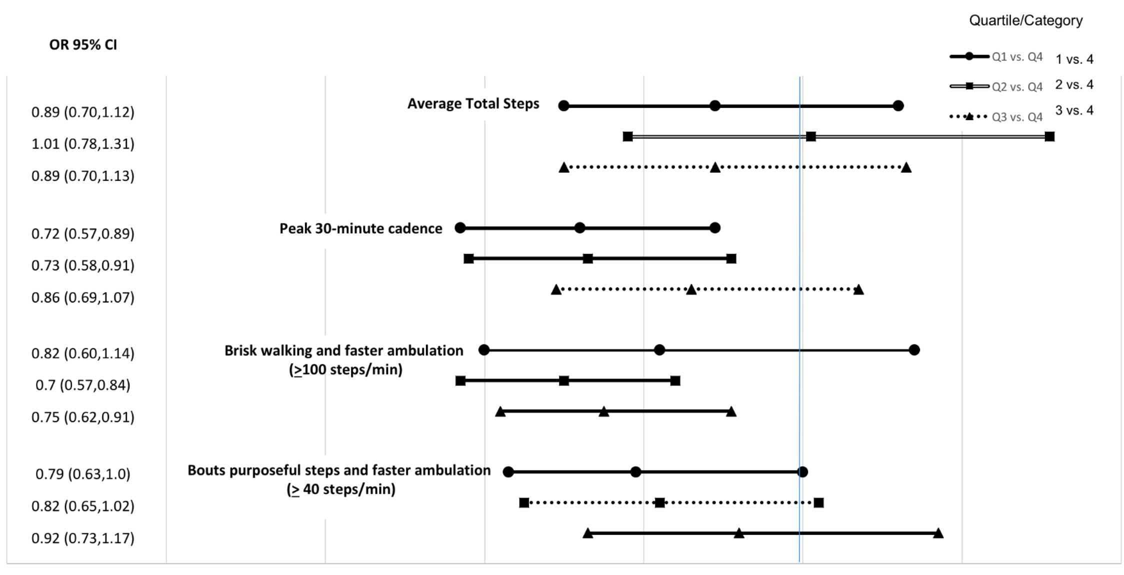

Fig. 5. The odds of substantially gaining weight and 95% confidence intervals in quartiles/categories 1–3 of step-based metrics compared to quartile 4 between baseline and visit 2; HCHS/SOL (2008–2017).

taking as few as 5,000–7,499 steps/day had lower baseline adiposity than those with < 5,000 steps/day. Similarly, adults who spent more average daily time in bouts of purposeful steps and faster ambulation had lower baseline adiposity than those with less time. Contrasting to cross-sectional findings, adults with faster peak 30-min cadences and more time at faster cadences had greater gains in weight than adults with slower peak 30-min cadences and less time at each cadence indicator. Similarly, adults who spent greater average daily time in at least ten-minute bouts of purposeful steps and faster ambulation had greater increases in weight and BMI over a six-year period than those who spent less average daily time. SB had no association with baseline adiposity or changes in adiposity. Relationships between minutes in incidental or sporadic movement and baseline adiposity were modified by age. Greater mean weight and BMI were found for those in higher compared to lower quartiles of incidental or sporadic movement among adults 60 + years.

Previous studies have found inverse cross-sectional relationships with adiposity and steps/day, (Hajna et al., 2018; Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015)and cadence7, (Tudor-Locke and Rowe, 2012; Sumner et al., 2020). Many prior studies were conducted on non-U.S. based populations17-19, (Jennersjö et al., 2012; Pillay et al., 2015; Mitsui et al., 2008), utilized pedometers rather than accelerometers17, (Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015), consisted of cohorts of<100 participants (Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015) and examined non-Hispanic populations (Chan et al., 2003; Sumner et al., 2020; Hajna et al., 2018; Hornbuckle et al., 2005; Thompson et al., 2004; Krumm et al., 2006; Jennersjö et al., 2012; Pillay et al., 2015). In support of these findings, we observed inverse cross-sectional relationships between steps/day, cadence, and adiposity but extend these findings to a large Hispanic/Latino U.S. based cohort.

Conversely our null findings for associations between step-volume and six-year changes in adiposity differed from previous studies including the AusDiab study (Dwyer et al., 2015) as well as randomized control trials of walking interventions (Oja et al., 2018). The AusDiab study demonstrated increments of 1,000 baseline steps were associated with a −0.06 decrease in BMI over a five-year period among Tasmanian adults (mean age, 51.4 years) (Dwyer et al., 2015). A *meta*-analysis of 37 randomized controlled walking interventions (mean ages, 30–72 years) reported declines in BMI over the trial periods (Oja et al., 2018). Contrasting findings between the current study and the AusDiab study may have been driven by differences between changes in steps over time. Over 33% of participants in the AusDiab study increased their step count and 16.7% remained in a high steps/day category (Dwyer et al., 2015). Due to collection of step-based metrics solely at baseline, we were unable to discern changes in steps over time for our analytic population. Intervention length may account for differential findings from the *meta*-analysis; intervention length ranged from 8 to 52 weeks whereas the current study examined a six-year observational period. Our results, however, align with the multinational Nateglinide And Valsartan in Impaired Glucose Tolerance Outcomes Research (NAVIGATOR) study, conducted with 2,811 predominantly Caucasian adults over three years, that found no relationship between prior step count and subsequent weight (Preiss et al., 2015). The NAVIGATOR study reported a median decrease in baseline steps of 372 steps/day (Preiss et al., 2015).

This definition of bouts applied to steps is unique. Previous epidemiologic studies have reported mixed associations when comparing moderate-to-vigorous PA accumulated in<10-minute bouts compared to accumulated in 10-minute bouts with adiposity outcomes (Strath et al., 2013; Loprinzi and Cardinal, 2013; Wolff-Hughes et al., 2015; Jefferis et al., 2016). We observed in our cross-sectional analyses that adults who spent more time in a bouted stepping cadence of purposeful steps and faster ambulation had lower weight, WC, and BMI.

Previously, in a cohort of older women, Lee et al. (2019) found inverse associations between steps/day and all-cause mortality were attenuated when step cadence was adjusted for steps/day. The present study found associations between step-cadence and adiposity, remained robust upon adjustment for total steps/day, suggesting an independent relationship between step-cadence and adiposity. Notably, Lee et al. examined peak 30-minute cadence as bouts and overall had slightly lower steps/minute ranges for each quartile which may explain differences in findings.

Our analyses found Hispanic/Latino adults with more time at purposeful steps and faster ambulation and faster peak 30-minute cadences had larger increases in adiposity than those with less time or slower peak 30-minute cadences. Over a six-year period, step cadence may have declined unevenly across baseline quartiles of PA. Steps/day and cadence may have declined more among those most active due to an inability to sustain levels of activity, resulting in larger gains in adiposity than those with less time at a faster cadence between baseline and V2.

Our study has several strengths. We studied a large diverse group of Hispanic/Latinos living in the U.S. with robust measures of adiposity and accelerometer measured PA. The step count function of the Actical accelerometer has demonstrated good validity at a typical walk (83 $m \cdot min^{-1}$) and run (133 $m \cdot min^{-1}$) speed (Esliger, 2007). Further, we controlled for multiple confounders that may have introduced bias. Our results should be considered in light of several limitations. Limitations of accelerometer measured step-metrics such as the inability to estimate upper body movements and activities such as cycling and swimming should be acknowledged. Longitudinal analyses examining change in adiposity are bound by baseline assessment of step-based metrics. Additionally, generalizability is limited to the HCHS/SOL cohort's target population of non-institutionalized Hispanic/Latino adults aged 18–74 years residing in the four sampled areas.

5. Conclusion

This study of accelerometer measured step-based metrics and measures of adiposity among the HCHS/SOL cohort demonstrated inverse cross-sectional relationships between steps/day and cadence with adiposity. Adults with faster cadences and more time at faster cadences gained more weight and had a higher BMI over six years than those with less time or slower cadences. Step-based metrics capture a broad spectrum of physical activities and are easily understood metrics that can be translated into public health guidelines and interventions. Additional longitudinal studies with follow-up measures of PA are needed to understand relationships between changes in PA and changes in adiposity over time and to extend these findings to other populations.

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CRediT authorship contribution statement

Samantha Schilsky: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Daniela Sotres-Alvarez:** Data curation, Writing – review & editing. **Wayne D. Rosamond:** Funding acquisition, Resources, Supervision, Visualization, Writing – review & editing. **Gerardo Heiss:** Funding acquisition, Resources, Supervision, Writing – review & editing. **June Stevens:** Supervision, Writing – review & editing. **Nicole Butera:** Methodology, Software, Writing – review & editing. **Jianwen Cai:** Methodology, Writing – review & editing. **Jordan A Carlson:** Writing – review & editing. **Carmen Cuthbertson:** Methodology, Writing – review & editing. **Martha Daviglus:** Writing – review & editing. **Madison N. LeCroy:** Writing – review & editing. **Amber Pirzada:** Writing – review & editing. **Kelly R. Evenson:** Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Sotres-Alvares discloses she had a relationship with the following

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Appendix A. Supplementary data

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